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Bridging the digital divide with low-cost information technologies

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Abstract.

Although there are many requirements that need to be met if the digital divide between rich and poor countries is to be narrowed, this paper focuses on just one aspect of the problem; namely, the need for low-cost information technologies that are suitable to the conditions prevailing in the latter rather than the former. It is argued that there are, in fact, already many more such technologies than most people realise, mainly because what information about them that does exist tends to be highly fragmented. What is needed, accordingly, is an institution charged with the function of registering and disseminating all the fragmentary information about low-cost information that is currently available.

Introduction

Few subjects nowadays are raised more frequently or with more urgency by leading international policy-making bodies than the 'digital divide' between rich and poor countries, i.e. the strikingly differential extent to which various forms of information technology are being exploited by developed, as opposed to developing, countries, as illustrated for example in Table 1. Though they differ with regard to how best to undertake the task, all these bodies agree that the divide needs to be bridged. In his Millennium Report, the Secretary-General of the United Nations, for example, refers to the need for 'building digital bridges' and he even goes so far as to suggest that: 'New technology offers an unprecedented chance for developing countries to "leapfrog" earlier stages of development. Everything must be done to maximize their peoples' access to new information networks' [1]. At much the same point in time, the Administrator of the United Nations Development Programme 'called on G-8 leaders in Japan . . . to help the developing world take full advantage of the Information Revolution. Speaking at a meeting of developing country leaders and development agency heads with G-8 leaders in Tokyo [he] stressed that the world has an historic opportunity and obligation to reach out and help the poor take advantage of Information and Communication Technologies (ICT)' [2].

It is not the intention here to review all the different areas of policy intervention (such as institutional reform, technological capability building, assistance to small-scale firms and so on) that would be required for this purpose. The more limited objective is to describe the role that low-cost forms of information technology might play in such an endeavour. For, although one can find scattered references to this type of technology in the literature, no attempt has yet been made to classify the various possibilities in a systematic and comprehensive manner, in spite of the fact that the cost of information technology (as indeed with most innovations emanating in, and for, the developed countries) is likely to be one of the main barriers to its more widespread diffusion in the developing countries

Table 1
The digital divide, 1998 [3]

	Internet hosts per 10,000 people	Share of world population (%)
Low-income countries	0.1	31
Middle-income countries	4.0	50
High-income countries	379.0	19

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and in spite of the fact that there are already far more low-cost versions of this technology than most people realise.

For the sake of convenience, this paper will begin by dividing these innovations into three main categories: telecommunications, computers (hardware and software) and electronic communication technologies such as e-mail and the Internet. Thereafter, however, it will be argued that because these categories are technologically interdependent rather than independent, low-cost versions of information technology tend to have a cumulatively positive, rather than a merely additive, effect on reducing the digital divide between rich and poor countries (assuming that policy is explicitly designed to capture synergistic effects of this kind).

Low-cost telecommunications technologies

Even with the advent of digital, as opposed to mechanical, technologies in the telecommunications sector, cost considerations remain central to the task of supplying telephone access to remote rural villages with low average incomes and low population densities (factors which help to account for the fact that, as shown in Table 2, urban areas of developing countries are usually far better served by fixed telephone lines than rural areas).

By far the most striking example of this approach is the design and manufacture of small-scale digital exchanges for rural areas in India. Against the background of a situation where, in 1980, 97% of that country's villages had no telephone at all, the motivation for leapfrogging to digital technology in general, and small-scale rural exchanges in particular, is best expressed in the words of the engineer who at the time most forcefully argued the case for this policy. 'My message', he wrote:

> . . . was that India should abandon electromechanical switching and move immediately toward digital systems for switching and transmission. My reasoning was twofold.
>
> First, electromechanical switching was ill suited to the Indian climate and to Indian conditions. With few available telephones, most lines were intensively used, and electromechanical equipment was much more likely than digital to malfunction from overuse. (We later discovered that some public phones in India generate as many as 36 calls per hour at peak volume, compared with maybe 10 to 12 in the United States.)
>
> Electromechanical switches are also more vulnerable to dust and moisture. Analog transmission, finally, suffers over distance, while digital transmission is what gives those astonishingly intimate connections halfway around the world. In a country with low telephone density like India, distance – and therefore static – were nearly unavoidable.
>
> Second, the development of digital technology would help build native industries in electronics, software, and related fields. Moreover, India needed one piece of digital equipment that no other country manufactured but that many developing nations could use: a small rural exchange. In the United States and Europe, the smallest exchange built will accommodate 4,000 to 10,000 lines, and, in small towns and rural areas, these exchanges are installed and then deliberately underutilised. This kind of waste may be tolerable in a country where the number of small exchanges is tiny. In India, exchanges with a vast overcapacity would have to be installed in hundreds of thousands of villages . . . Development of an efficient exchange for 100 to 200 telephones would not only solve India's problem, it would give the country a valuable high-technology export [5, p. 70].

Table 2
Percentage of total telephones lines in urban areas: selected developing countries [4]

Country	% urban lines, 1998
Angola	95.00%
Albania	97.00%
China	71.60%
Colombia	98.89%
Djibouti	100.00%
Eritrea	100.00%
Ethiopia	99.00%
Micronesia	70.00%
Guinea	98.00%
Libya	60.00%
St Lucia	100.00%
Mauritania	100.00%
Sudan	92.00%
Sierra Leone	87.00%
Surinam	80.70%
Syria	82.00%
Chad	81.31%
Togo	97.00%
Thailand	55.00%
Trinidad and Tobago	85.00%
Turkey	75.33%
Uganda	97.57%

Following an intense spate of activity on the part of the engineers who were involved in the (so-called C-Dot) project [6], what emerged in the late 1980s was not only a 128-line rural exchange, but also one that in several other respects as well was adapted specifically to Indian conditions. One of the problems associated with digital switching technology, for example, is that it produces heat and thus needs to be air-conditioned if it is to function reliably. To quote Pitroda [5, p.70] again:

In the countryside, the Indian electrical grid is notoriously undependable, and we couldn't give villages exchanges that were certain to overheat the first time the electrical system went down. The solution was simple but ingenious. First, to produce less heat, we used low-power microprocessors and other devices that made the exchanges work just slightly slower. Second, we spread out the circuitry to give it a little more opportunity to 'breathe'. The cabinet had to be sealed against dust, of course, but by making the whole assembly a little larger than necessary, we created an opportunity for heat to rise internally to the cabinet cover and dissipate.

Described thus, the Indian case clearly demonstrates that appropriate technology need not be confined to simple mechanical technologies, but can be applied also to modern, digital telecommunications systems in developing countries. Since its inception in the 1980s, moreover, the project to design small-scale rural exchanges has met with considerable success, as measured by the subsequent installation of 25,000 exchanges in the rural areas at a price per line (equal to some 1,500 rupees) 'which is one of the lowest for digital switches anywhere in the world' [7, p. 2]. The success of this project can also be measured by the fact that the technology has so far been exported to some twelve other, relatively poor, developing countries, mainly but not exclusively in Africa [8].

Just as digital switching technology can thus be high- or low-cost depending on its design, so too do particular circumstances determine whether satellites represent an appropriate or inappropriate form of communications for developing countries. On the one hand, for example, there are satellite systems that are designed for the minority of people who require more than the 20% coverage of the earth's surface now available through cellular phone networks. In response to this demand, a global satellite telephone network involving 66 low-earth-orbiting satellites was completed in 1998. Predictably, however, access to this global system comes at a high cost: 3,000 US dollars per handset and 1–3 US dollars per minute of service [9]. In contrast:

At the other end of the continuum are very cheap, store-and-forward satellite systems. One such system, Healthsat, uses a single LEO [low-earth-orbiting satellite] to provide communications to health care providers in Africa and other developing regions. The satellite passes over at least once per day; messages can be transmitted in bursts while the satellite is within view before disappearing over the horizon. The system is used for electronic mail and transmission of text, such as articles from medical journals [10].

Let us now turn to yet another and rather different example of how modern telecommunications technology can be adapted to the needs of developing countries. The technology in question is known as 'wireless local loop' (WLL), which was originally designed to provide narrowband telephony services in developing nations that lacked a telephone infrastructure. WLL is a system that connects subscribers to the public telephone network using radio signals, rather than copper, for all or part of the connection between the subscriber and the switch. The advantage of this technology is based on the recognition that:

Cost is the main constraint which prevents cellular from being a viable alternative for first-time telephone users in developing countries. One alternative is to strip away some of the functionality of a mobile cellular system to reduce its price. This has given rise to a radio-based access technology – generically referred to as 'wireless local loop' (WLL) – that provides an alternative to the traditional way of connecting subscribers to the local telephone exchange using copper wire. Data suggest that the cost of WLL has declined over time, making its price competitive with copper wire. As a critical mass of users is reached, the cost of WLL systems should fall even faster. WLL's low implementation and operating cost promises to significantly alter the expense equation of building telephone networks, resulting in lower tariffs and enhanced affordability for potential subscribers [9, p. 6].

In fact, according to one recent study [10], WLL would probably have been a lower cost alternative to the cell phones that are currently being used in one of the most prominent attempts to bring digital telecommunications to rural areas in developing countries; namely, the Village Phone project in Bangladesh run by Grameen Telecom, which enables members of the Grameen Bank to lease the phones for village use. The point is that:

While Village Phone uses a GSM system (the cell standard in most of Europe and Asia) . . . 'fixed wireless loop' systems . . . are less expensive to construct. GSM towers only reach 5 kms, but wireless local loop users can travel 50 kms from their towers, meaning many fewer wireless loop towers are needed to cover a country and the system is less expensive to build. Thus technologically Grameen Telecom's GSM system is in fact probably not the most cost effective way of getting universal telecommunications into these villages [12, p. 4].

Given, however, that GSM was the first technology to arrive, it has effectively 'locked-out' the less expensive WLL system, which, in contrast to the former, is a relatively new technology. Part of the reason for this comparative newness, in turn, 'is that in developed regions, wired local access has been more than adequate, rendering wireless networks commercially useful only for mobility purposes. Only with recent deregulation has WLL gained popularity as a viable competitor for the local loop with copper-based incumbent operators. In developing regions where wired infrastructure is scarce, WLL promises to be a viable alternative' [13].

In fact, as with digital switching technology, WLL has also been modified (much more recently) by an Indian telecommunications company to make it cheaper and more appropriate to conditions in the rural areas of the country. Known as 'corDect', the modified WLL:

> . . . is all set to usher in a rural telecom revolution in India by paring the cost of rural telephony by well over 50 percent, besides pegging the maintenance cost including power charges to a bare minimum . . .
>
> The project, started in January this year [2000] has wired 50 villages . . . successfully without using a single centimeter of copper wire . . . WLL, using the radio communication platform, connects the subscriber to the main exchange by radio waves instead of traditional wire loop . . .
>
> In the case of rural connections, while the cost per connection using conventional technology will be in the range of Rs. 40,000 to well over Rs. 130,000 in the remote villages with rocky terrain, the cost per telephone using the . . . WLL technology will cost only Rs. 17–18,000 per unit [14].

Again, as with the Indian-designed digital switching technology described earlier, 'corDect' is being used in a number of other developing countries. In particular, 'the technology has now been licensed to a few companies in . . . Singapore, Tunisia and Brazil', while: 'Systems are operational in Madagascar, Fiji, Kenya, Tunisia, Argentina and Nigeria' [15].

Still other innovations designed to bring information to isolated areas in rural India have emerged from projects associated with the M.S. Swaminathan Research Foundation. The Village Information Project in Pondicherry, for example, uses a 'value addition centre' (where staff who are working in a centrally located village scan the Internet for useful information) as the hub of a local area network based on very high frequency (VHF) radio. The 'value addition centre' serves information shops in other villages that are equipped with a Pentium personal computer (PC) and an inkjet printer:

> The PC can be connected to the wireless network through a modem and a specially designed interface. Each shop also has a board to display bulletins received on email from the value addition centre . . . The shop volunteers, at their discretion, write in more news from the locality. The shop also enables a visitor to make a voice (phone) call within the region [16].

Low-cost computers: hardware and software

Even though it is conceptually possible to separate the hardware and software aspects of low-cost computers, it is often difficult to do so in practice because of the interrelatedness between them. Three examples with potentially far-reaching implications for developing countries will serve to illustrate the point.

The first case, involving an American company called New Deal Inc., concerns itself with extending the life of older, less-expensive (286 and 386) computers which are often discarded prematurely because of the demands imposed by ever more sophisticated software programs. New Deal addresses this problem of premature obsolescence by developing software for PCs 'with a design approach of "sustainable software" that enables it to enhance functionality without regularly obsoleting existing hardware' [17]. More specifically, this type of software is 'able to run effectively on any PC, from the latest Pentium III to the earliest 286 PC'. A recently designed educational software program, for example, contains all the applications that are needed to teach computer literacy and Internet use and yet requires only a 286 processor, 640K RAM and 9MB of hard disk space. When one considers that in the USA alone there are said to be more than 30 million functioning computers that could be donated to schools, it is difficult to overestimate the potential impact of this innovation on computer literacy in developed and developing countries alike. (With regard to the latter, there are already said to be significant New Deal initiatives in place in Southern Africa, the Middle East, Brazil and India.) To this potential one should add the fact that the use of open source (as distinct from proprietary) software can also serve to prevent the premature obsolescence of computer hardware in developing countries. In the Philippines, for example:

> A number of local schools are discovering that Linux can save them from inevitably increasing their tuition fees every time they have to upgrade their computer systems.
>
> Educators who discussed the advantages of Linux in schools . . . agreed that this free open-source operating system that can run on low-end machines can free them from the financial bounds of commercial software distribution and upgrades [18].

The second example, unlike the first, is designed specifically for the socio-economic conditions in India and, in this regard, it resembles the small-scale digital exchanges from that country referred to earlier. The so-called 'Simputer' was designed jointly by the Indian Institute of Science and a private company based in

Bangalore, ‘in an effort to bring the Internet to the masses in India and other developing countries’ [19]. Priced at below 200 US dollars, the ‘Simputer’ will enable non-literate users to browse the Internet using pictures; also, its text-to-speech capability will allow the Web content to be delivered in local languages. According to one source, ‘the designers have been able to achieve the sub-$200 price point since the electronic components used in the device are all off-the-shelf volume components, and the software is primarily open source software such as Linux’ [20]. (*Note*, in this connection, the more general point that expensive commercial software packages are not necessary for many applications. Linux, for example, is being installed in some 140,000 computer laboratories in Mexican schools, while Schoolnets in South Africa rely exclusively on public domain e-mail software and mail servers [21].)

Also intended to be priced at less than 200 US dollars is a so-called network computer that has recently been developed by a corporate spin-off of the US software firm Oracle. Known as the New Internet Computer, this device has no hard disk drive and runs on open source Linux, rather than the Windows operating system: two of the design features that account for its exceptionally low cost. The New Internet Computers come installed with a 56K bps modem and Netscape Web browser, which is all that is required for them to gain access to the World Wide Web. The first such products ‘will target educators and provide students with a more affordable alternative to a PC for accessing the Internet and e-mail’ [22].

Still another venture that provides computers to developing countries at a fraction of their usual price is associated with a South African-based company called Africom, which is providing refurbished computers at a price of between 300 and 400 US dollars. Africom has an arrangement with an American-based organisation that is paid a nominal amount for cleaning the hard drives of the used computers (which, upon arrival in South Africa, are refurbished in Cape Town by a group of some 40 employees). ‘Most of the computers are Pentiums, which are used in such companies as General Electric and banks, as well as post offices’ [23]. Africom’s goal is to supply 16,000 computers per month, as opposed to the current number of 1,000, and its intention is to supply these to schools.

Just how much the above initiatives will help to over-come the digital divide between, as well as within, countries is as yet difficult to say. In part, this will depend on whether and to what extent information about these devices actually reaches potential consumers in developing countries (a problem to which we shall return in the concluding section). Much will obviously also depend on whether enough energy, in one form or another, can be delivered to rural areas in developing countries, where the lack of computers is most pronounced. What is perhaps most promising in this regard is the use currently being made of state-of-the-art solar power by non-governmental organisations, such as the Solar Electric Light Fund and Greenstar, in a number of developing countries. The latter organisation, for example, is helping to recover the cost of installing nine photovoltaic panels in a West Bank village by putting the newly connected computer to use as a means of selling local products on the World Wide Web [24].

Low-cost communication technologies

In the previous section, the emergence of various types (and combinations of) computer hardware and software that are designed to lower the cost of gaining access to the Internet was described. Some of these involved the use of software that prolonged the life of older, less expensive computers, while others lowered the cost of the final product by the use of open source, rather than proprietary, software. What have not yet been considered here, however, are low-cost alternatives to the Internet itself. Although these alternative technologies are by no means perfect substitutes for full (TCP/IP) Internet connectivity, they nevertheless:

> . . . allow basic network services like e-mail and provide vast improvements over other, more traditional communications options such as fax, telex, and the postal system. These alternatives are based on ‘dial-up’ access over normal phone lines to computers that collect messages and, in turn, distribute them in a similar manner to other computers as necessary until they reach their final destinations. Networks that send messages ‘hopping’ from computer to computer are known as ‘store-and-forward’ systems, and include UUCP (Unix to Unix Copy Program) and the PC-based FidoNet. It is important to note that these are not ‘low technology’ systems; indeed, the software that instructs messages to be ‘packed’ together, compressed, and sent complete with error detection and correction are all features that contribute to the low cost of the systems is quite sophisticated [25].

FidoNet, moreover, provides still another reason for rejuvenating older, discarded PCs from the developed countries that were mentioned earlier in connection with the new, more versatile software manufactured by the New Deal Inc., for: ‘While Internet and other high-technology computer networks require powerful machines, even some old, outmoded personal computers can run FidoNet programs, providing a communications link that is as fast as a telex – at a fraction of the cost' [26]. Here again, therefore, as in some of the previous examples, there is scope for breaking the costly process of becoming 'locked in' to a cycle of mutually determined increases in the sophistication of computer hardware and software.

When transition to the full Internet occurs in developing countries (on the approximate scale shown in Table 1), it may often be in an institutional context (such as a school, telecentre or office) where, more often than not, one encounters the problem that there are more computers available than Internet connections (i.e. that people have to wait in turn to go online). There are, of course, various solutions to this problem, e.g. ordering another telephone line or wiring the computers together, but, in practice, these may be either unavailable or too expensive. Recently, however, two major computer manufacturers have brought out a device that, for a few hundred dollars, allows wireless communications between multiple computers and the Internet (within a certain radius) [26]. In a classroom setting, for example, one could provide wireless communications to computers near a 'base station' located in a laboratory or hallway nearby.

Cumulative gains from alternative types of low-cost information technology

So far, the various forms of low-cost information technology have been treated as essentially independent innovations, thereby implying that the gains derived therefrom are merely additive in character. According to this view, for example, small-scale digital rural exchanges yield only direct gains by virtue of the wider access to telephones that they allow. In fact, however, the various elements of information technology that have been described above (i.e. telecommunications, computers and electronic communications) are closely connected and, to this extent, the potential for cumulative gains arises.

When it is combined with one or other of the low-cost computers described above, for example, telephone access via small-scale digital exchanges can deliver not just the direct gains already noted, but also a connection to e-mail or even the Internet itself. More generally, if policy makers are to maximise the benefits of low-cost information technology, they will need simultaneously to promote all the different forms that this takes. Moreover, such concerted policy action, in turn, is more likely to occur when knowledge about the range of technological alternatives is available from one source, rather than, as now, in highly fragmented form. In fact, there appears to be an urgent need at present for a single institution or registry that keeps a record of, and tracks, the entire range of low-cost innovations in information technology, originating as they do in developing as well as developed countries, public as well as private sectors and non-government as well as other types of institutions.

For example, whereas many of the innovations described above are the result of engineers working in India, some of the most prestigious academic institutions in the developed countries are also engaged in research designed to overcome the digital divide. The LINCOS project at the MIT Media Laboratory, for instance, aims to assist disadvantaged communities in developing countries with gaining access to, and using, information technology applications such as telemedicine, electronic trade and educational computer science.

Conclusions

As its point of departure, this paper took note of the widespread attention that is currently being paid in international policy-making institutions to the 'digital divide' between rich and poor countries. The intention in this paper has not been to address all the important policy issues that would be relevant to bridging this divide. For, while many such issues have already been extensively debated in the literature (such as the need for liberalisation in the telecommunications sector or the establishment of various types of telecentres), it has been argued that there is very limited awareness of the rapidly increasing scope for using low-cost versions of information technology in developing countries. Much of this lack of awareness is, apparently, due to the fact that there is currently no single institution charged with the responsibility for recording and tracking such technologies, emanating as they do from a very wide variety of different sources in developed as well as developing countries and including not just innovations in telecommunications, e-mail and the Internet but also in computer hardware and software. As a result, what information there is tends to be highly fragmented and difficult to access even with electronic data-search technologies.

It follows from this analysis that progress towards bridging the digital divide could be made merely by the establishment of an institution whose function would be to collect and disseminate all the fragmentary information about low-cost information technology that is currently available (though the author is fully aware that the potential afforded by such technology may often fail to be realised as a result of countervailing social and political factors in developing countries). Precisely what form such a registry would take is not an issue that the author wishes to address at this stage. It is, however, discussed at length in the accompanying paper in this issue of *Journal of Information Science*.

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References and notes

[1] United Nations, *We the Peoples: the Role of the United Nations in the 21st Century.* Millennium Report of the Secretary General of the United Nations, 2000, available at: www.un.org

[2] Reported in *UNDP Chief Warns G-8 Leaders of Widening Digital Divide*. Available at: www.unesco.org (21 July 2000).

[3] Source: United Nations Development Programme, *Human Development Report* (UNDP, New York, 2000).

[4] Data supplied by the International Telecommunication Union (ITU) of the UN, December 1999.

[5] S. Pitroda, Development, democracy and the village telephone, *Harvard Business Review* 71(6) (1993) 66–79.

[6] C-Dot refers to the Centre for Development of Telematics.

[7] *Voice and Data* (1996).

[8] From: www.cdot.com

[9] Partly for this reason, the satellite project funded by Iridium World Communications proved a failure. See *The Economist* (9 October 1999).

[10] H. Hudson, *Global Connections* (Van Nostrand Reinhold, New York, 1997).
The non-governmental organisation known as Volunteers in Technical Assistance (VITA) has long been investigating the use of low-earth-orbiting satellites in developing countries. In December 1999, it announced the signing of an agreement with several commercial companies that hopefully will allow the consortium 'to bring low cost email services to rural and isolated areas of developing countries' (see www.vita.org). According to the Director of Informatics at VITA: 'Low-end wireless technologies, including small communications satellites in low earth orbit (LEO) with concomitant low-cost ground-based hardware, can make dramatic impacts in isolated and rural areas, especially in the developing countries of Asia, Africa and Latin America'. See G. Garriott, *Low Earth Orbiting Satellites and Internet-Based Messaging Services* (1996) at: www.isoc.org

[11] International Telecommunications Union, *Executive Summary*: *World Telecommunications Report* (ITU, Geneva, 1998).

[12] C. Burr, *Grameen Village Phone: Its Current Status and Future Prospects* (International Labour Office, Geneva, 2000).

[13] M. Kibati, *What is the Optimal Technological and Investment Path to 'A Universal' Wireless Local Loop Deployment in Developing Countries?* Available at: www.isoc.org

[14] *The Financial Express* (1 November 2000).

[15] TeNet, The Telecommunications and Computer Networks Group, Indian Institute of Technology, Madras, *corDect: The Cost-Effective Wireless Local Loop Technology*. Available at: www.tenet.res.in/cordect/cordect.html

[16] M.S. Swaminathan Research Foundation, *Knowledge System for Sustainable Food Security*. Available at: www.mssrf.org

[17] From: www.newdealinc.com
See also the article entitled *New Deal, Inc. Announces New Deal Schoolsuite 98*, available at: www.3rdray.com

[18] From the article *Computer World Philippines: Freeware OS Attractive to Schools*, available at: http://linuxtoday.com.

[19] From the article *A Simputer Aims at the Developing World*, available at: www.pcworld.com
See also *Times of India Online* (August 2000) at: www.timesofindia.com and the Simputer FAQ at: www.simputer.org

[20] See www.pcworld.com

[21] M. Jensen, *Models for Sustainable Internet Development in Nigeria*. [Paper presented to the Internet Society, Nigeria Chapter, 1999.]

[22] From *Ellison Launches (Another) Network Computer Firm*, available at: www.nwfusion.com See also *Oracle to Offer $199 Network Computers* at: www.canada.cnet.com and *Understanding Network Computers* at: www.usfca.edu

[23] B. Ngoro, *One Man's Junk is Another's New Hardware* (2000), available at: www.highwayafrica.orgza/pages/africom.html

[24] Available at: www.self.org and www.greenstar.org

[25] American Association for the Advancement of Science, Sub-Saharan Africa Project, *Electronic Networking for West African Universities*. Available at: www.sas.upenn.edu

[26] J. Young, *Global Network: Computers in a Sustainable Society* (Worldwatch Institute, Washington DC, 1993).

[27] 'AirPort' is manufactured by Apple Computer Inc. (www.freebase.sourceforge.net); 'Residential Gateway' is from Lucent Technologies (www.wavelan.com).